

LARGE HADRON COLLIDER (LHC) – ATLAS AND CMS

\$20,500,000
+\$500,000 / 2.5%

Large Hadron Collider Funding

(Dollars in Millions)

FY 2020	FY 2021	FY 2022	Change over	
			FY 2021 Estimate	
Actual	Estimate	Request	Amount	Percent
\$20.00	\$20.00	\$20.50	\$0.50	2.5%

Brief Description

LHC, an international project at the European Organization for Nuclear Research (CERN) laboratory in Geneva, Switzerland, is the world's most powerful particle accelerator. It produces the highest energy particle beams ever created at a laboratory, making it the premier facility in the world for research in elementary particle physics. LHC is a superconducting accelerator ring approximately 16.5 miles in circumference, in which counter-circulating proton beams can collide with a total energy of up to 14 TeV (one TeV= 10^{12} electron volts). The collisions occur at four discrete interaction points around the circumference of the accelerator where highly sophisticated detectors measure the characteristics of the debris produced in the proton-proton collisions. LHC can also collide beams of heavy ions, such as lead.

Scientific Purpose

LHC probes the fundamental structure of matter to elucidate the basic forces that have shaped our Universe since the beginning of time and that will determine its fate. Among the possible unknowns are extra dimensions of space, unification of fundamental forces, and evidence for dark matter candidates in the Universe. Studies are carried out by colliding protons and heavy ions at extremely high energies and recording, reconstructing, and analyzing the by-products of these collisions using two large detectors: A Toroidal LHC Apparatus (ATLAS) and the Compact Muon Solenoid (CMS).

The discovery of the Higgs boson in 2012 was one of the original goals of LHC and is one of the most important discoveries of the last 50 years in particle physics. Now the scientific focus has shifted to understanding the detailed properties of the Higgs boson and other known processes to elucidate possible deviations from expectations — deviations that might indicate new phenomena. In addition, LHC continues to search for new particles and interactions, including supersymmetry, dark matter, and other unknown phenomena.

This scientific focus has motivated the High Luminosity (HL) upgrades to LHC and its detectors, which will allow for the collection of a much larger data sample. NSF is supporting upgrades to ATLAS and CMS as part of a large global effort (See the HL-LHC narrative in the MREFC chapter for more information).

Status of the Facility

LHC is the only experimental particle physics facility operating at the high energy frontier. The facility and the planned HL-LHC upgrades are a high priority of the entire high energy physics community. LHC energy upgrade in 2015 from 8 TeV to 13 TeV pushed the boundaries of our understanding into unknown territory. CERN is carrying out a multi-year program to increase the beam interaction rate that will culminate with HL-LHC operation beginning in 2027. This will produce a large data sample of rare events that could shed light on new physics. Installation of smaller-scale detector upgrades, now nearing completion, will enable ATLAS and CMS to keep pace with LHC's performance enhancements through 2024. A two-year shutdown planned to begin in 2025 will enable the installation of major upgrades to the accelerator and

detectors preparatory to ten years of HL-LHC operation, extending the scientific reach of the facility.

COVID-19 impacts on the operation program have been relatively minor so far. Ongoing activities at CERN to prepare the ATLAS and CMS detectors for the next cycle of accelerator operations, scheduled to begin in February 2022, continue to make good progress. U.S. scientists and international colleagues conduct hands-on detector support activities that follow carefully orchestrated protocols to ensure worker safety. Additionally, NSF support for LHC detector operation is concentrated in the software and computing areas, which have continued to operate according to pre-pandemic plans and are fully meeting expectations.

Meeting Intellectual Community Needs

Currently, more than 1,200 U.S. researchers participate in the ATLAS and CMS collaborations, including more than 100 post-doctoral fellows and more than 400 students, of whom about half are undergraduates. The U.S. researchers comprise about 25 percent of the total membership of the ATLAS and CMS collaborations. NSF supports about 20 percent of the U.S. ATLAS and CMS contingents (plus about 30 of the nearly 1,300 members of LHCb collaboration, which operates the separate LHCb experiment at LHC). Research at LHC is supported by NSF through the PHY Elementary Particle Physics and the Nuclear Physics programs.

In addition, a world-wide cyber-infrastructure, the Worldwide LHC Computing Grid (WLCG), is dedicated to LHC data processing, allowing scientists to remotely access and analyze vast data sets. The U.S. ATLAS and CMS collaborations continue to lead the development and exploitation of distributed computing within their respective international collaborative efforts. The WLCG Tier 1 and Tier 2 computing centers (funded by DOE and NSF respectively) enable the researchers at 92 U.S. universities and five national laboratories to access LHC data and computing resources and thus train students in both state-of-the-art science and computational techniques.

Governance Structure and Partnerships

NSF Governance Structure

NSF oversight is provided by a program officer in the MPS Division of Physics (PHY), who works cooperatively with staff from other MPS divisions, the Office of Budget, Finance, and Award Management (BFA), the Office of the General Counsel (OGC), and the Office of Legislative and Public Affairs. Within BFA, the Large Facilities Office (LFO) provides advice to program staff and assists with agency oversight and assurance. The MPS facilities team and the Chief Officer for Research Facilities also provide high-level guidance, support, and oversight.

External Governance Structure

NSF/PHY staff and their Department of Energy (DOE) Office of Science counterparts meet twice yearly with CERN and funding agencies from other nations at Resource Review Board (RRB) meetings, where technical and financial issues are discussed and decided. Each experiment is funded by more than forty different agencies, including NSF and DOE. NSF and DOE coordinate U.S. investments in LHC through a Joint Oversight Group (JOG), which also meets at least semi-annually.

The U.S. ATLAS and U.S. CMS collaborations internally select leadership that represent the United States within the international ATLAS and CMS collaborations. The international leadership for each collaboration establishes its respective scientific goals and objectives and exercises overall governance. NSF supports detector operation through two awards—one to Princeton University for CMS, and another to Stony Brook University for ATLAS. The current awards expire in December 2021 and January 2022, respectively, and the U.S. collaborations have each identified the universities that will steward NSF's anticipated subsequent five-year operations awards.

Partnerships and Other Funding Sources

U.S. activities at CERN are enabled by a DOE/NSF/CERN agreement signed in 1997 (“Experiments Protocol I”) and a Cooperation Agreement, signed in May 2015 and renewed every five years. An additional agreement signed in December 2015 (“Experiments Protocol II”) further defined the framework for NSF participation in the particle physics programs of the ATLAS and CMS detector collaborations under the auspices of CERN. These activities include expanding the physics reach of the detectors through construction of technologically advanced enhancements able to take full advantage of the increase of the LHC accelerator's nominal luminosity by a factor of ten. The resulting increase in capabilities will facilitate and support the continued participation of the large U.S. particle physics community engaged at LHC during the HL-LHC era. The HL-LHC is slated to operate for ten years beginning in 2027.

Funding

Annual operations and maintenance funding covers the costs of NSF-provided detector components, software and computing, and contributions to a common fund to maintain shared detector infrastructure. Detector operation and maintenance are forecast to require future levels of effort like those needed to support the current apparatus. Data handling is an exception, where extraordinary efforts by CERN, the experimental collaborations, and funding agencies are planned on a global scale to support High Luminosity LHC operation beyond 2027.

Total Obligations for LHC

(Dollars in Millions)

	FY 2020	FY 2021	FY 2022	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Operations & Maintenance	\$20.00	\$20.00	\$20.50	\$20.50	\$20.50	\$20.50	\$20.50	\$20.50

¹ Outyear estimates are for planning purposes only. The current cooperative agreements end in December 2021 (CMS) and January 2022 (ATLAS).

The FY 2022 Request for the NSF LHC program is \$20.50 million. Funds will support operation activities by U.S. university-based researchers participating in high energy physics at LHC. LHC will restart in February 2022 and resume full-time operation in May 2022. This follows the successful conclusion of the three-year data-taking period in December 2018, and the start of detector maintenance and the installation of detector performance enhancements that began in 2019.

Reviews

NSF and DOE conduct separate and joint external reviews of operation and detector upgrade activities. Each agency is fully cognizant of the activities of the other partner, and recommendations from reviews are routinely used to inform ATLAS and CMS operations planning and the agencies’ oversight thereof. Two JOG review meetings per year assess operational performance, scientific and financial status, management issues, and plans for future activities. DOE and NSF conducted joint external panel reviews of ATLAS and CMS operations in May 2019. The next joint operations reviews are planned for January 2022. The most recent JOG was held in March 2021 and another is planned for October 2021.

Renewal/Recompetition/Termination

Operations awards for ATLAS and CMS were renewed for five years in January and February 2017, respectively. Future renewal is being conducted through a proposal-driven process that is currently underway. NSF plans to conduct an external review and cost analysis of each detector’s operations proposal in Q4 of FY 2021 and Q1 of FY 2022, respectively.

Major Research Facilities

NSF has no ownership of any part of the facility. No divestment is planned at this stage. CERN has taken responsibility for disposal of all irradiated apparatus at the conclusion of experimental activity.